



NASA SBIR 2022 Phase I Solicitation

Z10.05 Rotating Detonation Rocket Engines (RDRE)

Lead Center: MSFC

Participating Center(s): GRC

Scope Title

Rotating Detonation Rocket Engine (RDRE) Injector Response, Recovery, and Operation Dynamics

Scope Description

RDRE injectors require further study and novel solutions to combat major challenges that this high-performance engine cycle experiences. Technology development efforts are needed to better understand how to reduce backflow potential of combustion products as the high-pressure detonation passes over the injector orifices. A high impulsive diodicity for injector elements represents one means by which this may be achieved. Recovery dynamics at various equivalent pressure-drop conditions may hold the key to minimizing deflagration losses. This is particularly the case for liquid/gas and liquid/liquid bipropellants. It is well known that recovery of propellants to reach the chamber at the same time and equivalently participate in the detonation process is where the majority of detonation benefits would come from. Finally, new element schemes that effectively stand off the detonation from the injector face as well as evenly distribute and mix propellant without losing unburnt propellant from the critical region are desired. Standing off the detonation from the injector face would reduce the overall pressure gradient that the injector orifices would experience and thus reduce backflow significantly. Each of these tasks is needed, among others, to reduce overall operating pressures to meet more reasonable liquid engine system requirements.

An ultra-high-performance detonation injector solution that attempts to resolve these challenges or address similar challenges is needed. Computational fluid dynamics modeling (CFD) and analysis in conjunction with cold-flow test, and finally hot-fire testing, would be highly desirable depending on the phase of the work. Solutions that resolve these challenges would afford NASA and the industry partner a feasible path forward to radically improving combustion device performances, enabling future mission architectures, including Moon to Mars.

This subtopic seeks innovative engineering solutions to the problem of injector response and detonation dynamics in the RDRE cycle with applicable propellants. Liquid/gas and liquid/liquid propellant phases are of primary interest, with particular interest in using cryogenic phase propellant. Methane, hydrogen, RP-1, hypergolics, and their subsequent phases are of primary interest to NASA. Gas/gas phase injection is not acceptable unless both liquid oxygen and fuel are in cryogenic states and both being used to regeneratively cool hardware.Â

Expected TRL or TRL Range at completion of the Project

2 to 5

Primary Technology Taxonomy

Level 1

TX 01 Propulsion Systems

Level 2

TX 01.4 Advanced Propulsion

Desired Deliverables of Phase I and Phase II

- Hardware
- Analysis
- Research
- Prototype

Desired Deliverables Description

Phase I is multifaceted and could include multiple development pathways. A feasibility study that demonstrates proof of concept for the given application is needed. This can be accomplished with CFD or other type of analysis that shows high diodicity injector schemes can be effectively employed in detonation engines. Further demonstration of manufacturing practicality of complex injector geometries will also be required. One way to do this would be to produce subscale injector orifices, potentially using additive manufacturing techniques. Conventional machining techniques could also be used to produce single-element flow specimens of various geometries. These orifices and specimens could then be subjected to a shock or simulated detonation. The injector's response and recovery dynamics would then be measured. Visualization and measurement of backflow or backflow resistance would be very helpful in this regard. Cold-flow testing using water or air as propellant simulants would be the norm. New techniques for production, postprocessing, and operation of injector orifices would be ancillary but a major addition to the work as it would demonstrate reduction of cost and schedule for hardware development.

Phase I requires small-scale laboratory demonstration using cold-flow experiments and/or modeling efforts to show proof of concept. Proof of concept could include demonstration of elevated diodicity potential for specific injector element geometries over a baseline comparison case. Metrics by which diodicity can be assessed include geometries that produce diodicity of >1.4 . However, there are schemes that could reach a diodicity of $>10\times$ factor. Efforts to understand propellant rates of recovery are also critical.

Phase II would entail cold-flow testing with simulated shock/detonation conditions in a laboratory setting and/or heat sink/regenerative hot-fire testing that assesses injector response, recovery, and performances such as C^* , thrust, and/or visual diagnostics of combustion emissions that allow for the deduction of combustion efficiency. Thrust measurements are desired as well.

State of the Art and Critical Gaps

Propulsion system performance advancement is virtually at a standstill. In fact, industry is now sacrificing combustion performance and specific impulse improvements for manufacturability. RDREs represent a potential for dramatic improvement in ease of manufacturing, combustion device specific-impulse performance, and advancing U.S. space access capability. High-efficiency propulsion system concepts such as the RDRE are being investigated across the United States, and interest has never been higher. Thus, this work seeks to radically improve and expand the design and test capability of RDREs toward making space access more feasible and cost effective.

Relevance / Science Traceability

The research requested through this solicitation is relevant to many current NASA projects and programs, particularly for future use with HLS (Human Landing System), SLS (Space Launch System), and the Moon to Mars agency architecture. There is also direct applicability to RDRE ARDVARC (Additive Rotating Detonation Variant Rocket Chamber), RAMFIRE (Reactive Additive Manufacturing for

Fourth Industrial Revolution Exploration Systems), LLAMA (Long Life Additive Manufacturing Assembly, and ALPACA (Advanced Lander Performance Additive Chamber Assembly) programs at NASA Marshall Space Flight Center.

References

- B. R. Bigler, J. W. Bennewitz, S. A. Danczyk, and W. A. Hargus, "Rotating Detonation Rocket Engine Operability Under Varied Pressure Drop Injection," J. Spacecr. Rockets, pp. 1-10, 2020, doi: 10.2514/1.a34763.
- D. Lim, "Experimental Studies of Liquid Injector Response and Wall Heat Flux in a Rotating Detonation Rocket Engine," Purdue University Graduate School, 2019.
- G. S. Gill and W. H. Nurick, "Liquid Rocket Engine Injectors," NASA Spec Publ SP-8089. 1976.
- J. Hulka, "Design and Fabrication of Additively-Manufactured Injector Elements for an RS-25 Preburner," 2019.

Scope Title

Methodologies for Improving Rotating Detonation Rocket Engine (RDRE) Exhaust Thrust Capturing (Nozzle Design Optimization) and Mitigation of Losses

Scope Description

Innovative methods by which RDRE exhaust products can be optimally captured to produce ideal thrust at minimum hardware mass are desired. The traditional RDRE nozzle typically involves the use of an aerospike-like plug nozzle in the center body and cowl or outer body nozzle. It is not fully understood how to optimally capture the thrust of an RDRE given that the exit flow has kinetic energy losses from the oscillatory exhaust. Methods by which these losses can be recovered would be of interest. Furthermore, methods by which the oscillatory outlet flow could be minimized would also be highly desirable.

In addition to the expansion section described above, novel methods for chamber and subsequent throat design are of interest. It is well known that an abrupt area contraction causes deleterious impacts to the detonation's stability and thus causes a decrease in detonative performance, which is thought to cause a decrease in global engine performance. Further investments into geometries that do not hinder detonation performance but also increase specific impulse are desired.

Expected TRL or TRL Range at completion of the Project

2 to 5

Primary Technology Taxonomy

Level 1

TX 01 Propulsion Systems

Level 2

TX 01.4 Advanced Propulsion

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware

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Desired Deliverables Description

Phase I requires CFD modeling or equivalent analysis/experimental work that demonstrates loss minimization and thrust maximization in addition to attempts that reduce overall hardware mass and scale. The primary goal is to better understand how to design a coupled chamber and nozzle configuration for RDREs that will ideally produce thrust with minimized losses. Methodologies that investigate and assess how to best accomplish this end are a priority. One potential means by which this could be accomplished includes creation of a program that utilizes the method of characteristics to design a plug/outer nozzle configuration at specific design conditions.

Phase I requires modeling efforts to show proof of concept and a downselected geometry to manufacture and test. Proof of concept could include full CFD simulation or simpler analysis methodology over a baseline comparison case. The baseline could be a standard-practice straight annulus with plug nozzle designed using Bykovskii's relations [1,2]. Novel methods for reducing loss mechanisms will also need to be shown. These may include protruding channel geometries into the annulus that may act as stators.

Phase II would entail heat sink/regenerative hot-fire testing that assesses performances such as C^* , thrust, and/or visual diagnostics of combustion emissions that allow for the deduction of combustion efficiency.

State of the Art and Critical Gaps

Propulsion system performance advancement is virtually at a standstill. In fact, industry is now sacrificing combustion performance and specific impulse improvements for manufacturability. RDREs represent a potential for dramatic improvement in ease of manufacturing, combustion device specific-impulse performance, and advancing U.S. space access capability. High-efficiency propulsion system concepts such as the RDRE are being investigated across the United States, and interest has never been higher. Thus, this work seeks to radically improve and expand the design and test capability of RDREs toward making space access more feasible and cost effective.

Relevance / Science Traceability

The research requested through this solicitation is relevant to current NASA projects and programs, particularly for future use with HLS (Human Landing System), SLS (Space Launch System), and the Moon to Mars agency architecture. Advancement of liquid propulsion system specific impulse is also heavily dependent on nozzle design for the RDRE cycle.Â

References

- K. Goto, J. Nishimura, A. Kawasaki, K. Matsuoka, J. Kasahara, A. Matsuo, I. Funaki, D. Nakata, M. Uchiumi, and K. Higashino, "Propulsive performance and heating environment of rotating detonation engine with various nozzles," *J. Propuls. Power*, vol. 35, no. 1, pp. 213-223, 2019.
- S. Yetao, L. Meng, and W. Jianping, "Continuous detonation engine and effects of different types of nozzle on its propulsion performance," *Chinese J. Aeronaut.*, vol. 23, no. 6, pp. 647-652, 2010.
- M. Fotia, T. A. Kaemming, J. Hoke, and F. Schauer, "Study of the experimental performance of a rotating detonation engine with nozzled exhaust flow," in *53rd AIAA Aerospace Sciences Meeting*, 2015, p. 631.
- T. Smith, A. Pavli, and K. Kacynski, "Comparison of theoretical and experimental thrust performance of a 1030:1 area ratio rocket nozzle at a chamber pressure of 2413 kN/sq m (350 psia)," in *23rd Joint Propulsion Conference*, 1987, p. 2069.

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